Automated Measurement of Beam Parameters in the COSY Injection Beam Line

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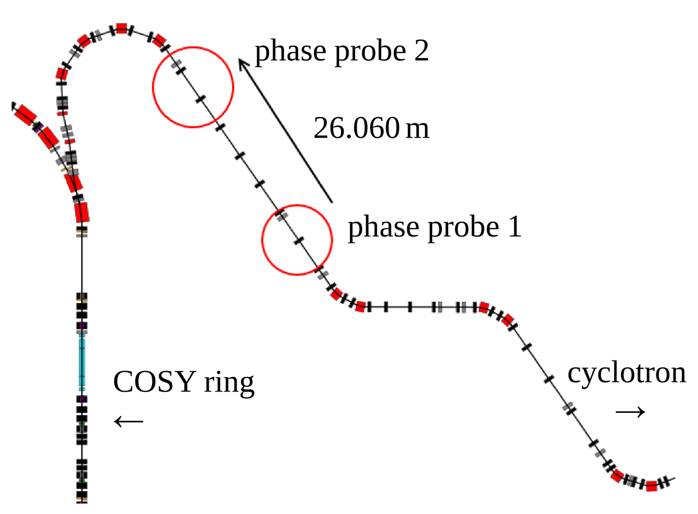
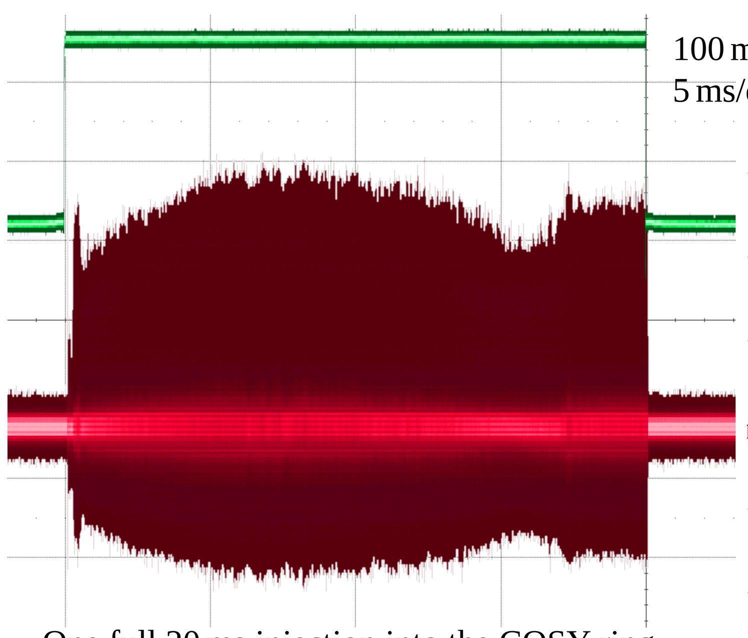
Abstract

The energy of the H[-] /D[-] beam injected from the cyclotron into the COSY ring is measured by means of two capacitive phase probes utilizing the time of flight method. The probes are installed in the long straight section of the injection beam line. In addition to the energy, other beam parameters such as bunch length, shape parameter and frequency can be obtained from the signals. Also the uncalibrated beam intensity can be extracted from the signals by integration. The signals from these probes are recorded and analyzed by means of an oscilloscope. The signal processing and analysis software running on the oscilloscope is written in Java. Since the software calculates the beam parameters automatically, it can be used for continuous monitoring and logging.

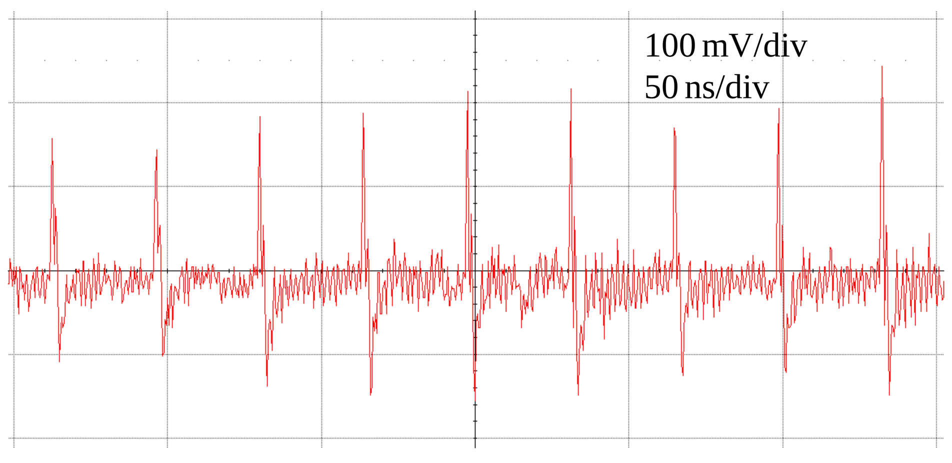


COSY injection beam line, where the phase probes are located.

Signal

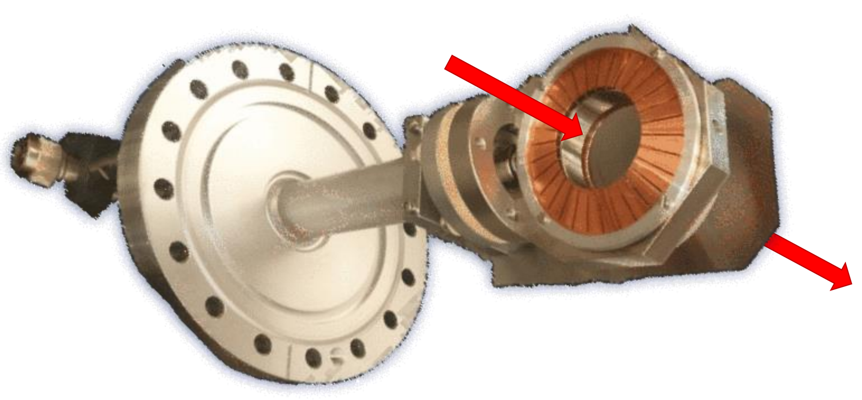


One full 20 ms injection into the COSY ring measured with one phase probe (red). The green signal is used as trigger.



A ~300 ns time window of the raw data acquired with one phase probe before the injection into the COSY ring. The response of single bunches can be observed every ~33.73 ns.

- Typical injection into COSY lasts 20 ms
- Bunch spacing of ~33.73 ns corresponds to the cyclotron frequency of ~29.6445 MHz
- ~600,000 bunches per injection
- Signal can be measured with up to 20 GS/s

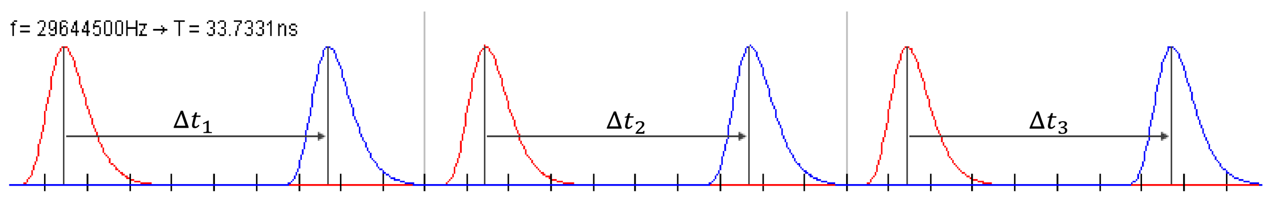


A capacitive phase probe type DB040rad [1], which is similar to the installed ones in the injection beam line. The beam is measured, while passing through the ring-shaped pickup.

Energy calculation

The energy is calculated from the time of flight between the two phase probes.

$$t_{flight} = \frac{N}{f} + \Delta t$$



Time of flight measurement for each pair of pulses.

– signal from phase probe 1
– signal from phase probe 2

- Pulses do not have to be from the same bunch
- Measured time has to be corrected by number of bunches between phase probes N over frequency f [2]
- An estimation for the energy is needed to calculate N (~45 MeV for H[-], ~75 MeV for D[-])
- Simulations yielded results with $\sigma_E \approx 10$ keV for E = 45 MeV

References

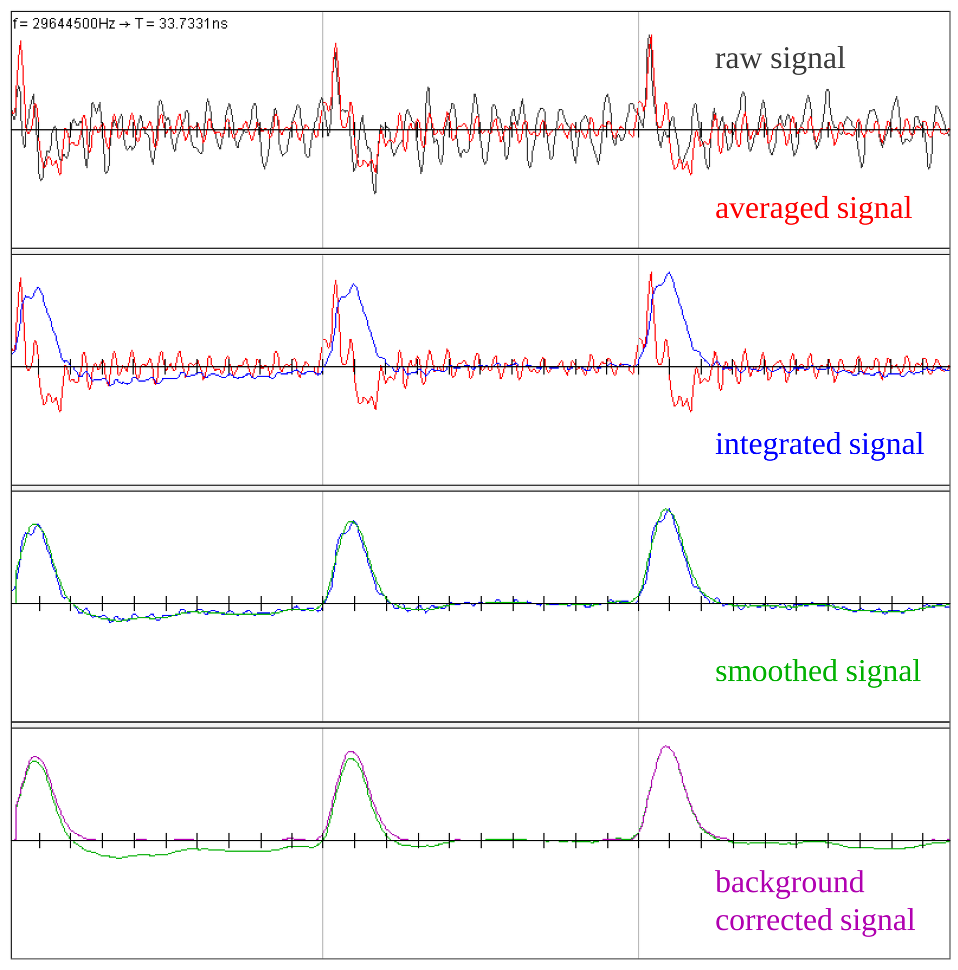
[1] NTG Neue Technologien GmbH, http://www.ntg.de/index.php?id=249

[2] Rainer Cee, Longitudinale Strahldiagnose mit Phasensonden am Heidelberger Hochstrominjektor, 1997

Signal Processing

In order to get the beam parameters out of the signal, it has to be processed in several steps:

- Averaging of multiple pulses to decrease noise
- Integration of the signal to restore the bunch shape
- Smoothing to further reduce high frequency noise
- Correct the background by connecting local minima with a polygon-line and subtract it from the signal



The different steps of data processing are visualized. The previous step is also shown to compare the differences.

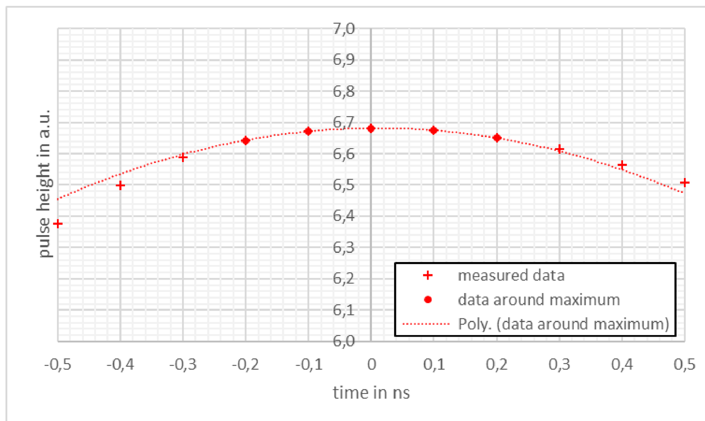
Beam Parameter Fit

Bunch Shape

The processed pulses are fitted using an asymmetric Gaussian function. The fit is done in two steps:

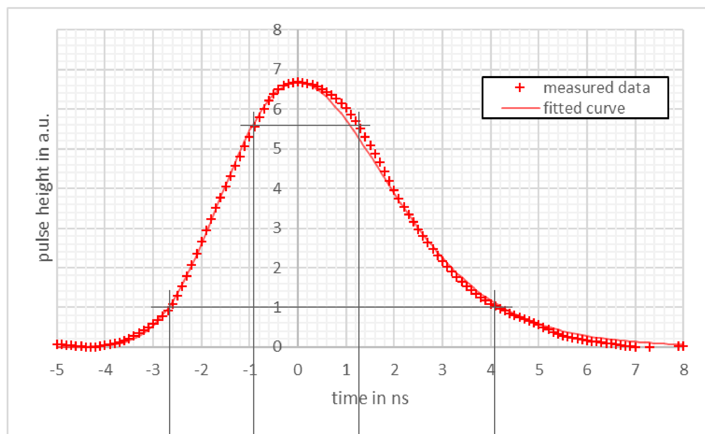
$$f(x) = A \cdot e^{-\frac{1}{2}\left(\frac{x-x_0}{m_\sigma \cdot (x-x_0)+\sigma_0}\right)^2}$$

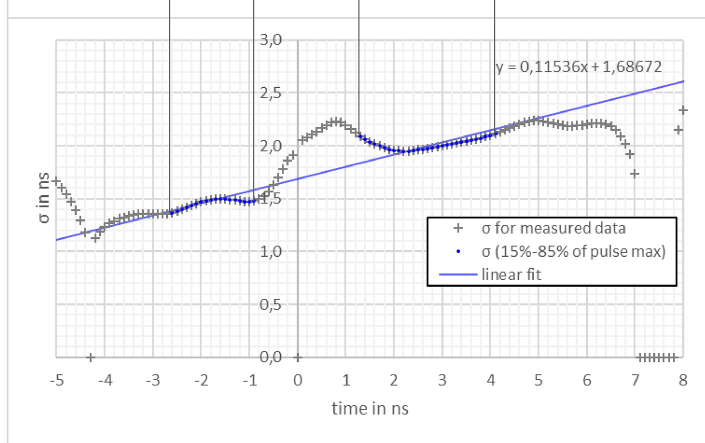
$$\Rightarrow m_\sigma \cdot (x-x_0)+\sigma_0 = \sqrt{\frac{(x-x_0)^2}{2 \cdot \ln\left(\frac{A}{f(x-x_0)}\right)}}$$



Zoomed view on the pulse maximum, where a polynomial 2nd degree is fitted to get x_0 and A.

- Maximum position x_0 and maximum A by polynomial 2nd degree around the peak value
- Asymmetry m_σ and bunch length σ_0 by linear function





σ is calculated for all points. To avoid undefined regions, only σ between 15% and 85% of A are used for the linear fit.

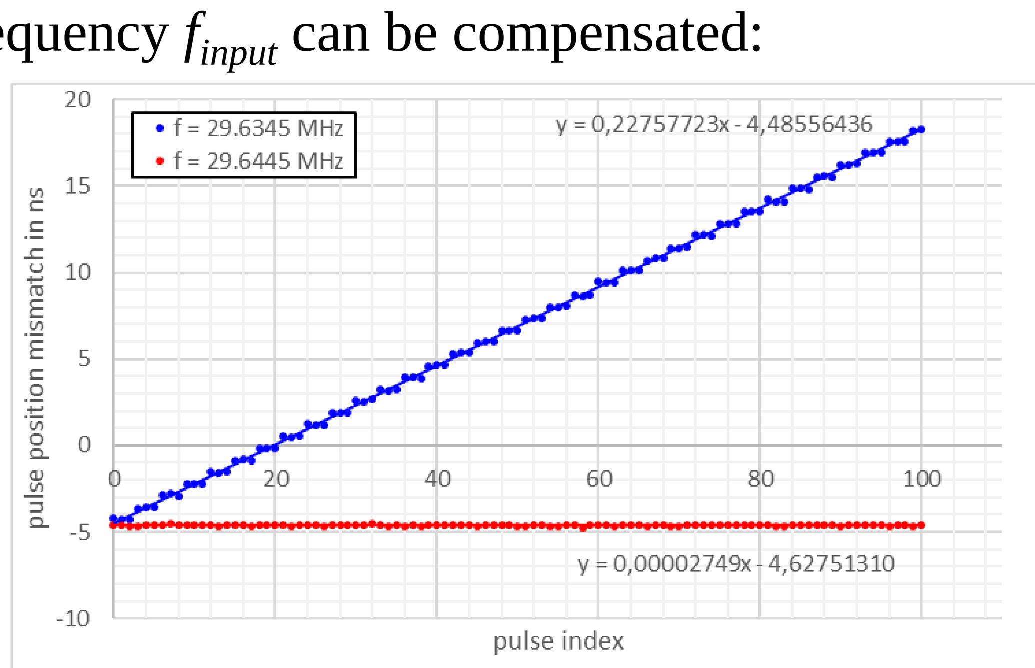
The x_0 parameters of two phase probes are used to calculate the beam energy with the time of flight method for each pair of pulses. The mean and uncertainty values are saved and displayed by the software.

Frequency

A slightly incorrect input frequency f_{input} can be compensated:

- Signal processing using estimated frequency (± 0.1 MHz)
- Pulses' positions will be shifted after averaging
- Position mismatch over pulse index is linear
- More precise frequency calculated using slope m over averaging steps p

$$f_{corrected} = \left(\frac{1}{f_{input}} + \frac{m}{p}\right)^{-1}$$



The same set of simulated data is averaged with two different frequencies. For the red curve the actual frequency is used. The frequency deviates -0.01 MHz from the actual one, which causes the pulses to shift over time.